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ELECTRONIC PROCESSES IN LIQUID XENON*

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This letter points out several basic errors that appeared in a recent article by Prunier et al. These errors relate to the analysis of data taken in liquid-xenon single-wire cylindrical chambers.

Several basic errors appeared in an article recently published by Prunier et al. entitled *Some properties of xenon liquid-filled nuclear detectors*[1]). The article describes an experiment to measure electronic phenomena in liquid xenon using single-wire cylindrical chambers. We describe below some errors made in their interpretation of their experimental observations.

1) Prunier et al.[1]) incorrectly analyzed their collected charge vs applied voltage data by assuming that the *observed* charge collected in their single-wire proportional chamber is equal to the *total* charge separated in the avalanche. In general these two charges are very different. For many years this difference has been known to exist in the analogous situation of gas-filled proportional chambers. In addition, our group in Berkeley has taken similar data and performed an analysis to determine the recombination of the initial ionization and the first Townsend coefficient as a function of electric field[2, 3]). A rigorous analysis[3]) shows that only approximately 10% of the avalanche charge is induced in the first 2 μs and that the avalanche electrons only contribute approximately 10%.

The following calculation will illustrate this point: At a typical electric field of 1.5×10^6 V/cm the mean free path for an ionization collision ($\lambda_c = 1/\alpha$) is (0.35 ± 0.05) μm, taken from ref. 3. We believe that value to be more reliable than the value of 0.5 μm reported in ref. 1 (fig. 6), but the choice does not materially affect the argument. The avalanche may be closely approximated as the abrupt separation of an electron charge Q and an equal Xe^+ ion charge at an effective distance λ_c from the surface of the wire (the location of the center of gravity of the avalanche). The electrons drift to the wire at their saturated drift velocity[4]) of 3×10^5 cm/s, in a time 10^{-10} s. During this time, a charge of only $0.012\,Q$ is induced at the anode[5]) (assuming an anode diam. of 7.5 μm and a cathode diameter of 10 mm). An even larger fraction of Q is induced by the outward motion of the Xe^+ ions during the first 2 μs (a typical pulse-shaping time – the calculation is very insensitive to this value). During 2 μs, the Xe^+ ions move outward[6]) 5.1 μm and induce an additional pulse of $0.11\,Q$. The Xe^+ ion mobility[7]) is 3×10^{-4} cm^2/Vs. The remaining charge ($0.88\,Q$) will be induced *after* the pulse has peaked, during the 0.74 s required for the Xe^+ ions to reach the outer electrode.

The authors do not mention their pulse rise time or the mobility of Xe^+ ions, essential factors for the interpretation of their data.

2) Prunier et al. ignore the recombination of the initial electrons and Xe^+ ions, a process that occurs very soon after the passage of the recoil electron. As determined in ref. 3, $((26 \pm 2)\%$ of the charge is lost in liquid xenon through recombination[8]) at 280 V/cm, the average field in the chamber of Prunier et al. at the applied potential of 500 V. This is in agreement with the "gain" of 0.75 shown in fig. 5 of their paper at 500 V, assuming an uncollimated source. We conclude that although the reduced pulse heights observed by Prunier et al. at low voltage could in part be due to impurities, nearly all of the effect is due to recombination.

3) In section 4.2, it is explained why break-down should occur at gains of 65–100, in agreement with observation. This agreement can only be due to cancelling errors, since in reality there are approximately *ten times* as many avalanche electrons (and Xe^+ ions) as Prunier et al. assumed. Our analysis[3]) shows that the secondary emission coefficient γ is less than 3×10^{-4}, in contradiction to the claim of

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Prunier et al. that γ lies between 10^{-2} and 1.5×10^{-2}.

4) There are several errors relating to the electron capture coefficient β. From the work of Swan[9]) and Miller et al.[4])

$$\beta/P_0 = A/E,$$

where β is the capture probability per mm drift, P_0 is the oxygen concentration in liquid argon, E is the electric field, and A is a constant. The value $A = 7$ per (mm V cm^{-1} ppm) given by Prunier et al. in section 4.1 is incorrect in both magnitude and units. The correct value is $A = 700$ V cm^{-1} per (mm ppm) which is evident from the original data shown in fig. 7. Furthermore, all left-hand vertical scale markers in fig. 6 should be multiplied by 10 [so that $A = 500$ V cm^{-1} per (mm ppm) for O_2 in liquid xenon]. We also point out that the horizontal scale in fig. 9 should read V/cm rather than kV/cm.

5) In section 1, paragraph 4, it is stated that (when sufficiently purified) the rare gas solids and liquids, and semiconductors are the only known condensed dielectrics in which electrons remain free. Prunier et al. are apparently unaware of research performed over many years with room-temperature hydrocarbons[10, 11]). Note that above 5 kV/cm, electrons travel faster[11]) in $Si(CH_3)_4$ than in any liquefied noble gas.

Although there are serious errors in their analysis, the raw experimental data of Prunier et al. are in substantial agreement with ours. For several years our group at Berkeley has been operating liquid-xenon-filled single-wire proportional chambers[2, 3]), multi-wire ionization chambers[12]), and multi-wire proportional chambers[13–15]). Recently, we have obtained images of distributed γ-ray sources, using lead collimators and a 24-wire liquid-xenon proportional chamber[15]). This rapidly expanding technology offers unique possibilities for studies of the electronic states of simple liquids as well as important applications in particle physics and medicine.

References

1) J. Prunier, R. Allemand, M. Laval and G. Thomas, Nucl. Instr. and Meth. **109** (1973) 257.

2) R. A. Muller, S. E. Derenzo, G. Smadja, D. B. Smith, R. G. Smits, H. Zaklad and L. W. Alvarez, Phys. Rev. Letters **27** (1971) 532.

3) S. E. Derenzo, T. S. Mast, H. Zaklad and R. A. Muller, Lawrence Berkeley Laboratory Report LBL-1313 (1973), submitted to Phys. Rev. A.

4) L. S. Miller, S. Howe and W. E. Spear, Phys. Rev. **166** (1968) 871.

5) H. H. Staub, in *Experimental nuclear physics* (Vol. 1, ed. E. Segré; J. Wiley, New York, 1952) p. 16.

6) H. H. Staub, p. 35 of ref. 5.

7) H. Davis, S. Rice and L. Meyer, J. Chem. Phys. **37** (1962) 947.

8) Experiments have shown that the fraction of electrons escaping recombination can be represented by $(1+K/E)^{-1}$, where E is the electric field, and $K = (1100 \pm 200)$V/cm for minimum ionization tracks in liquid argon [John Marshall, Rev. Sci. Instr. **25** (1954) 232] and $K = (98 \pm 12)$V/cm for minimum ionization tracks in liquid xenon (ref. 3).

9) D. W. Swan, Proc. Phys. Soc. **83** (1968) 659.

10) P. H. Tewari and G. R. Freeman, J. Chem. Phys. **49** (1968) 4394; and **51** (1969) 1276.

11) W. F. Schmidt and A. O. Allen, J. Chem. Phys. **50** (1969) 5037; and **52** (1970) 4788.

12) S. E. Derenzo, A. Schwemin, R. G. Smits, H. Zaklad and L. W. Alvarez, Lawrence Berkeley Laboratory Report LBL-1791, to be published in the Proc. 1973 Intern. Conf. on *Instrumentation for high-energy physics*, Frascati, Italy (May, 1973).

13) H. Zaklad, S. E. Derenzo, R. A. Muller, G. Smadja, R. G. Smits and L. W. Alvarez, IEEE Trans. Nucl. Sci. NS-**19** no. 3 (1972) 206.

14) H. Zaklad, S. E. Derenzo, R. A. Muller and R. G. Smits, IEEE Trans. Nucl. Sci. NS-**20**, no. 1 (1973) 429.

15) S. E. Derenzo, T. F. Budinger, R. G. Smits, H. Zaklad and L. W. Alvarez, Lawrence Berkeley Laboratory Report LBL-2092, to be published in the Proc. Symp. on *Advanced technology arising from particle physics research*, Argonne National Laboratory, Argonne, Illinois (May 17, 1973).